Lloyd's Interference Lithography System Employing Beam Shaping Technique for Wafer-scale Nano-patterning

Han-Jung Chang, Ping-Chien Chang and Yung-Jr Hung*

Department of Photonics, National Sun Yat-sen University, No. 70, Lienhai Rd., Kaohsiung 80424, Taiwan, R.O.C.
yungjr@mail.nsysu.edu.tw

Abstract: An expanded and top-hat light intensity distribution is generated in a Lloyd's mirror interferometer to realize an uniform 2D grating with a circular geometry and a 2.5% filling factor variation over the entire two-inch wafer.

OCIS codes: (160.4670) Optical materials; (220.4241) Nanostructure fabrication

1. Introduction

Laser interference lithography (LIL) has been an effective and inexpensive approach for generating submicron periodic patterns in one-dimension or two-dimension over a large area with high throughput. Among various configurations, a Lloyd-mirror configuration has been used for a wide range of applications due to its simplicity in system setup and the control of pattern periodicity [1]. However, inherent Gaussian distribution of the laser beam leads to a non-uniform grating pattern formation, especially for wafer-scale patterning using a single-beam Lloyd's mirror interferometer [2]. The grating uniformity can be improved by employing a two-beam interferometer setup, but this approach lacks the simplicity for tuning the pattern periodicity [3]. In addition, the use of a two-beam interferometer only reduces the impact of non-uniform light field to the resultant resist grating profile. The on-wafer geometry variation of the resultant grating still exists. Converting the Gaussian intensity profile of a laser beam into a more uniform distribution seems to be a straightforward solution to this issue. Although various beam shaping techniques are therefore developed in the past years [4-6], none of the interference lithography system reported in the literatures utilizes such beam shaping devices to achieve a flat-top intensity profile of the laser beam for uniform nano-patterning. In this work, a refractive beam shaper is utilized in a Lloyd's mirror interferometer to achieve wafer-scale patterning of one-dimension (1D) and two-dimension (2D) periodic structures with a uniform resultant profile. Though many papers had mentioned the possibilities to utilize beam shaping techniques to solve the non-uniform Gaussian intensity distribution of a laser beam in LIL, to our best knowledge, it is the first time that this idea is indeed employed in a LIL system. As a result, it is also the first time that an uniform periodic structure on a two-inch wafer is demonstrated. For practical application, the LIL system has been widely utilized to realize Bragg grating for single-wavelength semiconductor distributed-feedback laser production. The on-wafer grating uniformity strongly affects the laser performance. Therefore, we believe that the proposed LIL system will be promising for not only semiconductor laser industry but also the fields that require an uniform periodic structure.

Figure 1 (a) The schematic diagram of the proposed LIL system. (b) The intensity distribution of an expanded laser beam with or without beam shaping.

2. Experiments

The schematic diagram of the proposed LIL system is shown in Figure 1(a). In this system, a 355-nm diode-pumped solid-state laser having a output power of 20 mW is utilized as the light source in the proposed LIL system. This laser is not only cheaper than most gas lasers but also allow a compact size. A tunable beam expander and a refractive beam shaper are then utilized to convert the Gaussian intensity profile of a laser beam into a flat top one for the following beam expansion. The sample holder is positioned 25-cm away from the UV objective in order to
obtain a sufficiently large light field for covering the entire sample stage. Figure 1(b) shows the intensity distribution of an expanded laser beam with or without beam shaping. We can clearly observe that after light expansion a top-hat laser beam can provide a uniform light field area \( (L = 12.5 \text{ cm}) \) that is two times larger than that provided by a Gaussian laser beam \( (L = 5.5 \text{ cm}) \). The results indicate that the distance between the UV objective and sample holder can be closer if a top-hat light field is utilized in the LIL system, thus decreases the loss of the laser energy.

To validate the advantages of top-hat beam profile in Lloyd's mirror interferometer, an expanded light field with a Gaussian or top-hat intensity distribution is utilized as the UV light source in the LIL system for comparison. 2D resist grating structures are realized by double exposure of two-beam interference and the rotation of sample by 90 degree before the second exposure. Theoretically a 2D periodic structure with a circular geometry will be realized if the same exposure energy is used for the double exposure. Otherwise, the variation in the filling factor (FF) and ellipticity \((e)\) of the resultant resist profile will be observed. In this experiment, a 160-nm thick antireflection coating is used to eliminate the standing-wave effect arise from the high interface reflection between silicon substrate and photoresist. As a result, the resultant 2D resist grating profile would loyalty reflect the spatial intensity variation of the incident light field. Figure 2 shows the photographs of the processed wafers and the zoom-in top SEM views of the resist grating profiles at the center and edges of the wafer fabricated by the Lloyd's mirror interferometer with and without beam shaping. The FF and ellipticity difference in the resultant 2D resist profile are 10.53\% and 0.59, respectively, as the incident light field has a non-uniform Gaussian intensity distribution. Such a geometry variation can be effectively reduced by using a top-hat incident light field. The experimental results indicate that the resultant resist profile has a FF and ellipticity variation of only 2.5\% and 0.06, respectively, throughout the entire two-inch wafer.

![With beam shaper](image1)

![Without beam shaper](image2)

**Figure 2** The photographs and top SEM views of the resultant 2D resist grating profiles on a two-inch silicon wafer fabricated by the Lloyd's mirror interferometer with and without beam shaping.

3. **Conclusions**

In summary, a refractive beam shaping technique is employed in the Lloyd's mirror interferometer for the first time in order to achieve uniform resist grating profile over a large sample area. With the help of a top-hat laser beam, we successfully double the uniform exposure area, thus the laser energy can be utilized more efficiently in a LIL system. Finally an uniform 2D resist grating profile with a FF and ellipticity variation of only 2.5\% and 0.06 over the entire two-inch silicon wafer is successfully demonstrated.

**Acknowledgements**

This work was supported in part by the Ministry of Science and Technology, Taiwan, under grant MOST 102-2218-E-110-010, MOST 103-2221-E-110-038, and MOST 104-2221-E-110-061.

**References**
